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Electric Trams
Lessons Learned at Cape Cod National Seashore

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Report Notes and Acknowledgments

This Lessons Learned report is published by the National Park Service (NPS) Transportation Management Program (TMP) in the interest of documenting and widely sharing the experiences of national park staff in planning and implementing visitor transportation systems and services.

The perspectives presented herein primarily reflect views of National Park Service staff as these would be offered freely to their peers.

This report was prepared by the John A. Volpe National Transportation Systems Center, a unit of the U.S. Department of Transportation Research, Innovation and Technology Administration. It was funded by the NPS under Project Plan Agreement HW1M with the cooperation of the Federal Highway Administration Federal Lands Highway Office. Principal members of the Volpe Center project team were:

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In addition the team was assisted by Warren Osterberg of the U.S. DOT Research, Innovation and Technology Administration, who provided access to historical Advanced Vehicle Program (AVP) records. And, the team consulted Shang Hsiung of the U.S. DOT Federal Transit Administration, who was the designated Contracting Officer's Technical Representative on the Cape Cod Electric Tram project for the AVP.

The cooperation, assistance and insightful contributions provided by park staff and others are greatly appreciated.

Introduction

In seeking to obtain environmentally friendly replacement vehicles for its parking shuttle service, Cape Cod National Seashore set out to procure two hybrid-electric trams in 1998. Ultimately, battery-powered trams were delivered with multiple safety and performance problems that were never successfully remedied. This analysis examines the causes of these deficiencies and identifies several critical "lessons learned" that will assist other parks to avoid similar problems when undertaking future procurements of similar vehicles.

Scope and Structure of the Document

Following this Introduction, which provides an overview of the vehicle procurement process followed at the Cape Cod National Seashore (CACO), this document is divided into four sections: (1) a narrative account, coupled with a timeline, describing the procurement schedule and the life of the trams; (2) a description of tram safety and performance problems and causes; (3) lessons learned regarding effective project management for alternative fuel vehicles; and (4) lessons learned regarding vehicle specifications.

The U .S. Department of Transportation John A. Volpe National Transportation Systems Center (Volpe Center) conducted this analysis for the National Park Service. The goal of this report is to educate and inform parks that are procuring or considering procuring electric or hybrid-electric vehicles. Events at the Cape Cod National Seashore are used as an illustrative example, but the included lessons are applicable to all parks. The information used to develop this analysis was collected from available documentation and through interviews with the participating stakeholders. The Volpe Center appreciates their participation and forthrightness.

Overview

A growing number of National Park Service (NPS) units offer visitor transportation services as an attractive alternative to private automobiles. Use of alternative fuels to reduce ATS vehicle impacts on park environments is also becoming increasingly prevalent. The process of procuring alternative fuel vehicles, especially vehicles that require significant modifications from their original design, is complex and challenging. Most park units have little or no experience with alternative transportation acquisition and with alternative fuel vehicles in general. The challenges encountered by the national park staff at Cape Cod National Seashore provide useful lessons for future alternative fuel vehicle procurements.

Cape Cod National Seashore (in Wellfleet, Massachusetts) provides a shuttle service for park visitors between a parking area and Coast Guard Beach on the shore of Cape Cod. Hybrid-electric trams were desired by the park to provide environmentally friendly transportation for this service. Previously, Cape Cod National Seashore had operated propane trams that were obtained from the Everglades National Park. After several summers of use, the propane trams were in need of replacement. Diesel school buses were used as an interim option, but the NPS desired to implement a more environmentally sensitive means of transportation. Cape Cod National Seashore used funding from its vehicle replacement account to commission, through the Defense Advanced Research Projects Agency (DARPA) Electric and Hybrid Vehicle Technology (EHVT) Program, the production of two hybrid-electric trams on a 50%-50% funding basis with industry. The trams would use commercially available components, which shortly beforehand had been integrated in a bus that was at the time being demonstrated to public transit agencies around the country but not operated in a comparable setting to the planned Cape Cod National Seashore service.

From the time the trams were commissioned and when delivered, a number of significant changes were made to the design – regrettably most were made individually to address a particular issue or problem without due consideration of the potential for unintended consequences on overall tram performance. The most significant of these was the substitution of the hybrid-electric propulsion system with an entirely battery-electric system, due to the unavailability of the small natural gas power microturbine essential to the hybrid design. This change precipitated a number of other changes to the batteries, cooling system, and wiring, all of which were to have consequences for the ultimate performance problems and decommissioning of the trams.

When delivered to the Cape Cod National Seashore, the trams were met with a great deal of optimism and excitement. Over the first summer of use, however, soon it became clear that the battery powered trams had many shortcomings. The most apparent among these were a lack of sufficient power, inadequate range, and poor reliability. A great deal of time and money were expended attempting to remedy problems with the trams, working from inadequate repair manuals and inaccurate schematics. Repairs were barely able to maintain operability, and ultimately it became apparent that the trams would have to be removed from service.

Even after retiring the electric trams from service, Cape Cod National Seashore sought a cost-effective means to restore the trams to service given the popularity of the trams among park visitors. However, it had very little funding to invest in further repairs to the trams. In early 2002 the park asked the Volpe Center to find a university willing to re-engineer the trams. Students would benefit from the opportunity to work on the trams, and the park would only need to raise funds to pay for replacement parts. Several universities were considered in this regard, and a Cooperative Research and Development Agreement (CRDA) was executed with the Wentworth Institute of Technology in September of 2002.

In conjunction with coordinating the repair process, the NPS asked the Volpe Center to prepare this "lessons learned" document to help park managers with future procurements of alternative propulsion vehicles. The experiences at Cape Cod National Seashore serve as an illustrative example and the lessons would be applicable to any park. The Volpe Center used the conclusions from the Wentworth Institute of Technology reports as well as interviews with the park manager and park maintenance staff to identify several key issues related to the management of the project and to the design of the vehicles, listed below. Each of the issues is examined in greater detail in later sections of this report.

Lessons Learned: Effective Project Management for Alternative Fuel Vehicles

The Volpe Center reviewed the management of the project to determine why and how decisions were made during the design and construction processes, as well as why subsequent decisions concerning repairs and modifications failed to rectify the problems. Several important lessons can be learned from the Cape Cod National Seashore electric tram project to allow park managers to avoid the same pitfalls:

- Recognize that procuring an advanced technology vehicle involves risk.
- Identify performance needs for the expected vehicle usage and operating environment.
- Assess technology readiness and identify supporting infrastructure and documentation requirements.
- Set a realistic timetable, with a backup plan.
- Review proposed changes carefully, from an overall systems perspective.

- Provide methods for enforcing vehicle performance and quality requirements.
- Maintain good communication among all stakeholders.

Lessons Learned: Vehicle Design Specifications

The Volpe Center's analysis determined that no single, catastrophic defect caused the trams to be removed from service. Instead, the cumulative effect of multiple smaller problems, which exacerbated one another, resulted in the gradual degradation of tram performance. Through a series of incremental design compromises, the resulting trams simply were incapable of meeting the demands of the intended service. Several important lessons can be learned from the project to assist park managers with future vehicle acquisitions. Whereas the following lessons learned are drawn from the Cape Cod electric tram experience, many apply as well to any vehicle acquisition:

- Beware of deviations from planned vehicle specifications and technologies, as these can generate unintended and unexpected impacts on system performance and reliability.
- Specify sufficient motor power and vehicle range, recognizing that system performance may degrade over time under a rigorous duty cycle.
- List any special needs or operating conditions in the procurement specifications, and allow time for thorough inspection and testing prior to vehicle acceptance.
- Incorporate infrastructure requirements into the procurement specifications.
- Include maintenance training and accurate manuals in the procurement specifications.
- Ensure sufficient battery cooling capacity.
- Ensure the quality of wiring and grounding.
- Specify a suspension system that ensures safety during maintenance and repairs.

The lessons learned from this project come as a result of decisions made by all parties involved in the project. In the following pages the issues with the original tram design, changes made during the redesign process, and administrative shortcomings are examined to understand the failure modes behind the Cape Cod National Seashore electric trams and to help develop guidelines and recommendations for the successful acquisition of vehicles for visitor transportation, particularly with respect to electric or hybrid-electric vehicles, recognizing that many lessons learned apply to other types of vehicles as well.

Narrative

Stakeholders

The Cape Cod National Seashore hybrid-electric tram project involved multiple stakeholders. The roles of each are described below.

- As the designated NPS project manager for procurement, the **Chief of Maintenance** at Cape Cod National Seashore was responsible for the execution and oversight of the vehicle procurement process and for acting as liaison to other park staff. The project manager also was responsible for overseeing the operation of the trams after delivery. The park had a specialist mechanic and electrician who were responsible for maintaining the trams.

- The Defense Advanced Research Projects Agency (DARPA) **Electric and Hybrid Vehicle Technology (EHVT)** program was established in 1993 to pursue advanced vehicle technology research and development projects that have the potential to meet military needs while also having commercial potential. DARPA focuses on advanced technologies that have significant potential benefits, recognizing there are commensurate risks. The EHVT was conducted on a 50%-50% cost shared basis in cooperation with seven regional industry consortia. The EHVT was transitioned to the U.S. DOT Advanced Vehicle Program in 1998.

- **Electricore**,[*]. a private, non-profit consortium within the DARPA Electric and Hybrid Vehicle Technology program that served as "Administrative Program Manager and signatory for publicly funded research, development, deployment, and demonstration programs," and in particular for the Cape Cod National Seashore tram design and development project.

- **Advanced Vehicle Systems** (AVS) was a vehicle manufacturer, specializing in hybrid and electric vehicles. As a member of the Mid-America Electric Vehicle Consortium,[†] AVS was responsible for designing and constructing the trams and the support infrastructure. AVS also was responsible for procuring the necessary components from other companies and for making on-site repairs for all warranted parts.

- The **Advanced Vehicle Program** (AVP), established in 1998, was managed by the U.S. Department of Transportation (DOT) in collaboration with other federal agencies, including the Department of Defense and Department of Energy, private companies, research institutions, and state and local governments. The U.S. DOT **Research and Special Programs Administration** (which became the Research and Innovative Technology Administration in 2005) administered the AVP. A technical staff member of the U.S. DOT **Federal Transit Administration** (FTA) served as the program manager for the AVP.

Timeline

The timeline below details the steps, from initiation of the project to removal of the trams from service, for the hybrid-electric tram project. From start to finish, the scope of this lessons learned report spans six years during which there was active participation from two federal agencies and multiple private entities. Note that AVS, as agreed upon, delivered the trams approximately six months after the order was placed. The typical timeframe for delivery of transit vehicles is on the

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[*] Electricore brochure (http://www.electricore.org/img/ecorebrochure.pdf), p. 11
[†] AVS filed bankruptcy in April 2003; no representatives were available for interview in connection with this lessons learned research effort.

order of 12 months, and advanced technology vehicles or those incorporating design changes take even longer to produce.

Project Timeline
Source: Volpe Center

Date	Event
1995	Propane trams become unreliable. Cape Cod National Seashore starts looking to procure new trams
Jan 1998	AVS commissioned to construct two hybrid-electric trams
Feb 1998	AVS completes design and begins construction of the trams
Mar 1998	Capstone withdraws CNG turbine from transportation market
Mar 1998	Design changes to battery-only electric trams
May 15, 1998	Delivery deadline for first tram
Jun 1998	First tram delivered without road testing
Jun 15, 1998	Delivery deadline for second tram
Jul 1998	Second tram delivered without road testing
Oct 1998	Electric and Hybrid Vehicle Technology program is transitioned from DARPA to U.S. DOT / RSPA (now RITA).
Mar 1999	U.S. DOT AVP executes agreement with the Electricore-led consortium to retrofit the trams with microturbines in September 1999, after the summer park season.
Apr 2000	Retrofit concept abandoned because trams require new batteries to be able to be returned to service in the 2000 season; funding limitations forces choice of new batteries over the retrofit. Trams and rapid charger returned to AVS for evaluation and repairs.
Aug 2001	Cape Cod National Seashore electric trams retired from service after service during the 2000 and 2001 summer seasons.
Sep 2002	Cooperative Research and Development Agreement with Wentworth Institute of Technology for rehabilitation of trams for other uses.

Events

In the summer of 1995, it became apparent that Cape Cod National Seashore needed to replace the propane-powered trams it used to provide shuttle service to park visitors. The propane tram components were wearing out, and the vehicles were becoming increasingly unreliable. School buses were used periodically as substitutes for the propane trams, but school buses were not considered a long-term solution because of the difficulty for park visitors to load and unload their beach gear.

Over the next two years, the park undertook a fundraising process for new, alternatively-fueled vehicles, securing matching funding from through the DARPA Electric and Hybrid Vehicle Technology (EHVT). Under the EHVT, industry consortia agreed to match the funding provided by the NPS. Under the overall consortium leadership of Electricore, a relatively new vehicle manufacturing company, AVS[*], was commissioned in January of 1998 to design and build two open-air trams based off of an existing AVS 22-foot electric bus design.

The original AVS design concept was for hybrid-electric trams that ran on batteries and one (1) compressed natural gas (CNG) microturbine. The batteries would be recharged overnight with a trickle charger, while the microturbine would supply both additional power and sustain charge or recharge the batteries during normal operation.

From the outset the park wanted the trams as quickly as possible to replace the school buses being operated on an interim basis. This translated to pressure on AVS deliver the trams according to the schedule, regrettably to the eventual detriment of other considerations. During construction, multiple obstacles arose that necessitated significant modifications to the vehicle design in the interest of maintaining the schedule.

The staff of AVS encountered the first significant obstacle when they attempted to secure CNG microturbines in March of 1998. AVS had based their design on the Capstone microturbine that had been used in the prototype, but had not ordered any. At the time of construction, Capstone was no longer offering or providing support for the microturbine in transportation applications. AVS, unable to locate another microturbine model compatible with the tram design and facing a deadline, suggested a quick-fix solution: instead of the hybrid-electric trams proposed in the original design, they proposed fully electric trams, with mid-day rapid charging capabilities achieved through a fast-charger.

The second challenge was to enable the fast-charging capabilities, which required a high-voltage power source. A suitable power source was not available near the beach area, so the charger was installed at the Visitor Center, about one mile away from the tram service route. The charger was later moved to the nearby driveway of an elementary school, because there was not enough space in the Visitor Center parking lot to accommodate the trams and parking for visitors.

The construction of the first tram and battery chargers was completed in mid June of 1998, and construction of the second tram was completed in early July of 1998. The short timeframe within which AVS was to deliver the trams became an issue, because it prevented AVS from completing any road testing on either tram before delivery. The park was willing to accept the vehicles under these conditions with the expectation that problems would be corrected under warranty, even though this deviated from the terms of the original procurement specifications – a decision that served pressing needs yet proved regrettable in the long run.

When problems with tram performance and reliability began to occur, technicians had to travel from AVS in Chattanooga, Tennessee to assist the park staff in performing the necessary repairs or modifications to all warranted parts. The trams, while specified to be identical, had numerous differences including different models of motors. Neither tram conformed exactly to the original design specifications; consequently the supplied manuals and schematics were inaccurate. As a result, the available documentation was of limited use to guide the AVS technicians or the NPS maintenance staff in performing repairs on the trams. All maintenance was done on a trial and error basis that was both frustrating and time consuming.

The most significant post-delivery modifications to the trams were changes to the battery size and cooling system. The trams were originally delivered with 6-Volt batteries, which were water-cooled. The power source was later changed to 12-Volt batteries that were air-cooled. The reason for the change has been anecdotally reported that the water-cooling system was removed because

[*] AVS went out of business in 2003 and was unavailable for input or comment on lessons learned.

it did not fit in the battery compartment with the larger batteries. Although the switch to air-cooling accommodated the larger batteries, the air-cooling design was insufficient for the hot summertime operation, resulting in battery overheating* and significant degradation to tram performance.

After three seasons of use, the trams were removed from service and replaced with similar trams powered by gasoline engines. The battery packs had been replaced three times, the rapid charging times had deteriorated from 20 minutes to about one hour, and the capability to perform regular service had all but disappeared.

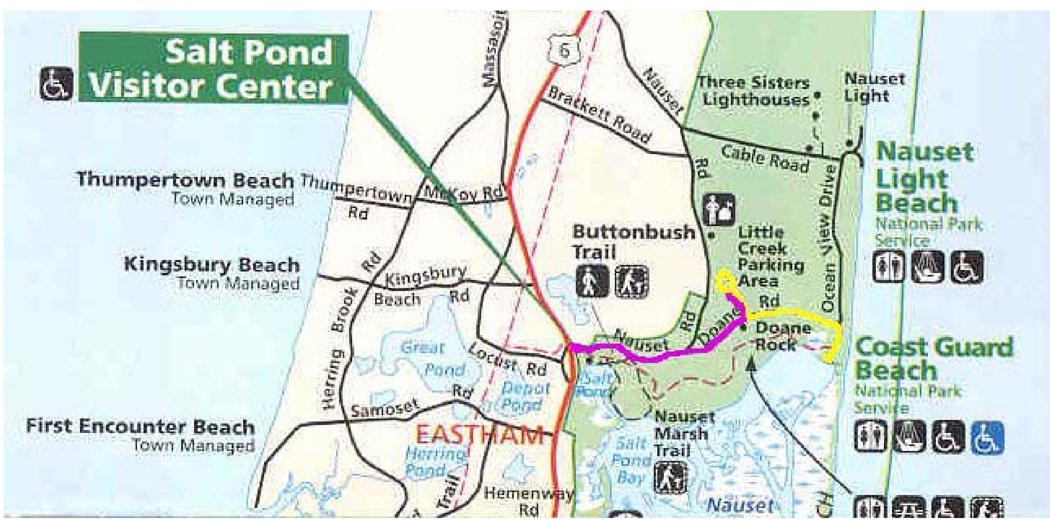
Tram Specifications

The vehicle specifications called for the trams to be capable of 60 miles of travel without refueling (at 70°F), to be able to climb a 9% grade, and to have completed 60 miles of road testing prior to the delivery dates, set for mid-May and mid-June of 1998.

Service Route

A map of the area surrounding Coast Guard Beach on Cape Cod is provided in Figure 1. The service route and parking area are highlighted in yellow. The circuit is approximately 1.8 miles round trip. The route to the fast-charger is highlighted in purple. The fast charger initially was located in the Salt Pond Visitor Center parking area, which is about one mile away from the Little Creek parking area that serves Coast Guard Beach.

Figure 1
Map of Coast Guard Beach and the Surrounding Area. The service route is highlighted in yellow. The route to the charger is highlighted in purple.
Source: Cape Cod National Seashore



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* Available project records do not indicate whether AVS realized the extent to which the cooling capabilities of the system would be reduced with the switch to air-cooling, and if so, whether this problem was communicated clearly to Electricore and/or the AVP and park staff.

Findings

The trams had multiple mechanical and electrical problems upon delivery, which increased over time. No single, catastrophic defect caused the trams to be removed from service. Instead, the cumulative effects of multiple smaller problems, which exacerbated each other, resulted in the gradual degradation of tram performance. The trams were ultimately removed from service due to sluggish performance, deteriorated batteries, unreliability, and safety hazards posed to passengers and maintenance crews (primarily the possibility of electric shock). This section examines the causes of these factors which resulted in the trams being removed from service.

Safety Issues

The trams presented several safety hazards for both the park maintenance staff and park visitors. Most of these were electrical hazards related to the fast charger and high-voltage systems on the trams. High voltage can be used safely as long as proper wiring safety precautions are in place and trained technicians maintain the systems. However, the high-voltage electrical systems on the trams did not fully conform with the National Electrical Code (NEC),and posed a safety hazard. Also, the trams lacked safeguards to protect maintenance staff working underneath the tram in the event of a sudden pressure loss in the air suspension system.

Fast Charger

A fast charger is a specialized battery charger that charges batteries at a rapid rate. The tram fast charger used high-voltage, high-current power and was designed to fully charge an entire battery pack in about 20 minutes when the batteries are more than 80% depleted. The charging process for the trams presented a safety hazard because the charger could not operate with ground-fault protection. In order to charge batteries safely, a charger must offer protection from a ground-fault, an electrocution hazard caused by an unintended electrical path between a source of current and a grounded location. A ground-fault circuit interrupter (GFCI) reduces this hazard by shutting down the electrical circuit when there is a problem. A GFCI continuously compares the current entering a device (the “hot” path) to the current leaving the device (the neutral path). If the two currents are different, a short has occurred and there is a current leak, which poses an electrocution hazard. A GFCI will also trip due to fire, overheat, or the destruction of wire insulation.

The use of a GFCI for the tram charging system is required by the NEC, but the park staff had to bypass the GFCI in order to charge the tram. When connected to the circuit, the GFCI would immediately trip when the charger was activated. The park electrician and the head electrical engineer from AVS both looked for the source of the current leakage on board the tram, but were never able to locate it. After the trams were removed from service it was discovered that the fast charger electrical protection feature had been installed improperly; the neutral and ground lines of the charger were both connected to the frame of the tram, which the GFCI interpreted as an electrical short circuit. Bypassing the GFCI, as park staff did, allowed the charger to operate, but negated the primary safeguard against an electrocution hazard. This was particularly dangerous when the tram charging station was moved to the elementary school driveway, a location where children and others possibly unaware of the hazard, were present.

Wiring

The tram wiring systems did not fully conform to the NEC. For example, high and low voltage wires were strung together. The safety procedures for working with high and low voltage are significantly different, so this practice was confusing to the maintenance staff and created a hazardous working environment.

In service, the wiring proved to not be sufficiently protected from the heat, humidity, sand, salt, and other hazardous environmental conditions at the Cape. The electrical wiring and connectors were exposed to water, salt, and debris from the environment. Many electrical connections had rusted and the insulation around wires had eroded, contributing to the electrocution hazard.

The batteries were located under the passengers' seats without an insulated barrier between the batteries and the seats. In addition, the connections between batteries were were exposed to the environment. Water or salt entering the battery plugs could have caused arcing since passengers returning from the beach may be wet and/or carrying wet belongings. Vehicle design safeguards to mitigate risks associated with locating batteries proximate to passenger areas are common in electric transit vehicles yet were not fully incorporated on the trams.

Suspension System

The air suspension system on the trams did not have a safety mechanism to keep the tram elevated when the system discharged. On one occasion the system emptied while a mechanic was working underneath the tram. Fortunately, the mechanic has a slight build and was able to fit in the space under the tram, and a bystander was able to extract him quickly. However, a larger person would have been seriously injured. After this event support jacks were placed to support the trams during all maintenance procedures, and no one was permitted to perform work on the trams alone. Air suspension system safeguards are appropriate for any vehicle that has one, and is not unique to electric and hybrid-electric buses or trams.

Power Issues

The limited power provided to the trams by the battery system caused a significant performance problem. Both trams had an extremely limited range, as well as poor acceleration and difficulty climbing hills. All of these problems worsened over time as the tram batteries and electric drive components degraded from being overstressed.

Acceleration and Hills

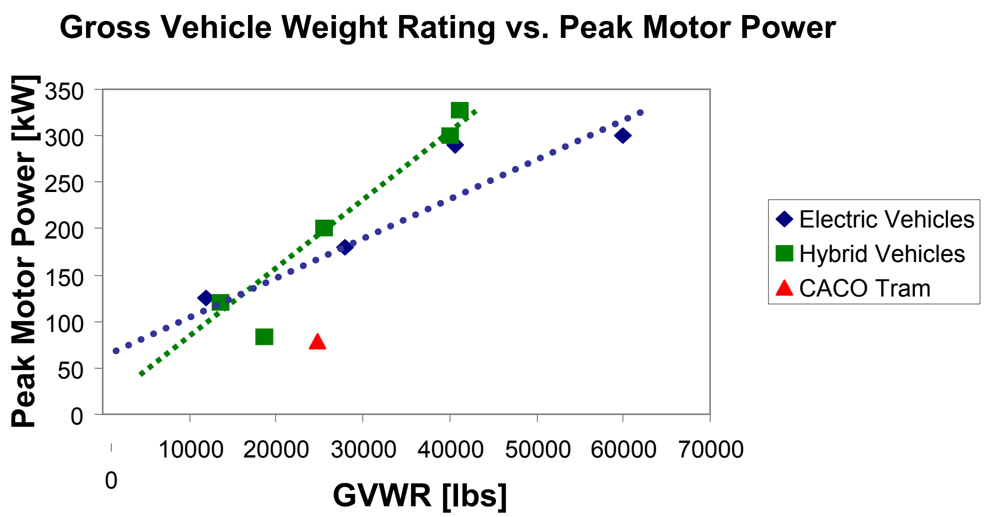
Cape Cod tram power was relatively low for its Gross Vehicle Weight Rating (GVWR – the maximum loaded weight, including fuel and payload). Figure 2 displays the power to GVWR characteristics of several heavy-duty hybrid and electric vehicles.[*] As is shown, vehicles with a higher GVWR have greater peak motor power.[†] The most comparable vehicle to the Cape Cod trams in Figure 2 is an open-air hybrid-electric vehicle without air-conditioning (just to the left of the Cape Cod trams on the chart). Although its GVWR is about 6000lb less than the Cape Cod trams, it has 10kW more peak power.

Compared to other electric and hybrid-electric vehicles of similar size, the Cape Cod trams are marginally powered – both in terms of the peak motor power and the ability of the battery pack to provide sustained peak power to the motor. This conclusion is supported by anecdotal evidence from the Cape Cod tram operators. Even though the second Cape Cod tram had a newer motor that was more efficient and provided greater power for the same input voltage, both trams had slow acceleration and difficulty climbing hills on the service route. A higher-power motor would

[*] Source: Department of Energy (DOE)
[†] It is important to note, however, that most of the data are for vehicles that use additional power for air conditioning, which the Cape Cod trams did not.

have been better for the GVWR of the Cape Cod trams and could have mitigated poor performance with respect to acceleration and climbing hills, but would have consumed more power and thus required more frequent recharging.

Figure 2
Comparison of the Gross Vehicle Weight Rating and Peak Electric Motor Power for Electric and Hybrid Vehicles
Source: Department of Energy (DOE)



Limited Range

The NPS trams had an extremely limited range. Under the best operating conditions with new, fully charged batteries, the trams could travel to and from the charging site and complete only six circuits of the service route, a total distance of about 12.8 miles, before requiring recharging. The specified driving range was 60 miles, which is more than four times the actual tram performance in the best conditions. AVS had made the park staff aware that without the microturbine the driving range would be reduced, but did not expect performance to be reduced so severely.

Removing the microturbine from the design simultaneously eliminated the on-board charging of the batteries during operation and increased the electrical current draw on the batteries. These two changes worked together to significantly reduce the range of the vehicles. A microturbine increases the range of an electric vehicle by sustaining charge or recharging the batteries during operation. Without the microturbine to sustain or recharge the batteries, the electrical current drawn from the batteries was greater. Given that batteries are depleted proportional to the square of the current draw,(i.e., doubling the current draw increases the rate of battery depletion four fold) the the range of the trams was decreased exponentially. Assuming that the trams could have completed the specified 60 miles as hybrid vehicles, these two changes could easily account for the limited range of the trams as delivered.

Decreasing Motor Performance

As time passed, the trams became increasingly sluggish. In part, the decreasing performance was due to the deterioration of the batteries. As the available energy decreased, the motors were forced to draw less power. However, even with new battery packs the performance of the trams was not restored fully. Because the motors were not designed to withstand the rigors of the Cape Cod environment; sand and salt had penetrated the housing of the motors, significantly reducing motor efficiency. As a result, even with fresh batteries the trams increasingly had difficulty with acceleration and climbing hills. The lower motor efficiency further increased the load on the batteries, thereby decreasing the range of the tram even further and accelerating deterioration of the batteries.

Battery Deterioration Issues

The gradual degradation of Cape Cod tram performance primarily was due to the deterioration of the batteries. Over three summers of service, the battery packs had to be replaced three times. When the trams were removed from service, the battery packs could only provide enough energy for the trams to complete one or two circuits of the service route per charge. The charging time had increased from 20 minutes to about 1 hour, and the problems with acceleration and hills had worsened. On one occasion the passengers had to get out of the first tram to enable it to climb a hill. All of these problems were caused by the deterioration of the batteries' capacity to store energy. The fast charger, excessive heat, over-discharging, and wiring deterioration contributed to damage the batteries.

Fast Charger

Rapid charging is accomplished by applying a high current during the beginning of the charge cycle, and gradually reducing the current as the battery approaches a full charge. This process can generate excess heat that damages the storage capacity of a battery not designed to withstand the higher temperatures. For this reason, lead-acid batteries to be used with a fast charger must be specifically designed for rapid charging. See Appendix 1 for additional details about how the rapid charging process can damage batteries. It is important to note, however, that although a mismatch between the tram batteries and the fast charger probably contributed to battery deterioration, the damage is more attributable to overheating that resulted from excessive current draw during tram operation.

The batteries supplied by AVS were designed for slow charging only, but this was not discovered until after the trams were removed from service. Even if the charger used the ideal current algorithms for rapid charging lead-acid batteries, the initial burst of high current power would heat up the conductive path, damaging the batteries that were designed for slow charging. Thus although NPS staff operated the charger as instructed, the frequent rapid charging of the trams effectively destroyed the batteries.

Excessive Heat

The lead-acid batteries used in the NPS trams are not designed to operate at high temperatures. Lead-acid batteries are designed to operate at 25°C (77°F) and will last for about 10 years. The expected service life of a battery decreases by half as the operating temperature increases by 8°C (15°F). The operating temperature of the batteries on the Cape Cod trams is not known, but with the high summer temperatures at the Cape (ranging from 24°C (75°F) on average up to 35°C (95°F) during July and August), the operating temperature probably was above ideal levels during much of the summer season

The battery ventilation system on the NPS trams was not capable of adequately cooling the batteries to compensate for the high temperature of the operating environment. Both rows of batteries in each tram were cooled at each end by plastic fans. However, such forced-air cooling is not an effective enough way to cool batteries in areas with high ambient temperatures[*]. The battery case materials have poor thermal properties, so it takes extended periods of time for the heat within a battery to dissipate with or without a ventilation system. Forcing hot air from the ambient environment over the batteries can also create temperature imbalances in the battery assembly if the cooling system is not properly designed. Batteries are very sensitive to heat, and temperature differences across a battery will decrease their efficiency and shorten their useful life. The battery ventilation system must be regularly inspected and maintained to ensure proper functioning. It appears that one or more of these factors contributed to the accelerated deterioration of the Cape Cod tram batteries.

Over-discharge

Under ideal conditions, lead-acid batteries should not be discharged below 20% of capacity before being recharged. In general, the more complete the discharge is, the more damage is done to the battery. Discharging batteries fully and then recharging ("deep cycling") repeatedly harms the batteries and significantly decreases storage capacity. A lead-acid battery typically can only provide between 200 and 300 full discharge/charge cycles before being rendered useless[†].

The limited range of the Cape Cod trams likely caused batteries to be almost fully discharged during each cycle. An indicator light would activate on the tram control panel when batteries needed to be recharged, but the tram would still need to complete its service route and then drive another mile to the charging station before recharging. The charge state that activated the indicator light was not documented, but considering the limited range of the trams, the batteries would almost certainly be well below their ideal recharge state by the time a tram reached the charging station if the charge indicator light came on while the tram was in service on the route and the batteries would sustain some damage in getting the tram to the charging station. Based on an expected lifetime of 200 to 300 full discharge/charge cycles and that the trams were charged about 4 times a day, this suggests a functional battery lifetime of 50 to 75 days, assuming full discharge/charge cycles.

Wiring

As discussed above, the wiring between batteries deviated from the NEC. High-voltage and low-voltage wires were strung together, creating hazardous repair conditions. In addition, the wiring systems were inadequately protected from environmental factors such as moisture and corroding agents. As a result, electrical connections between the batteries deteriorated, thus contributing to inefficient power distribution and uneven loading between the batteries within a pack. As a result, individual batteries were subjected to greater stress and needed to be replaced more often than anticipated. In addition to the replacement of three entire battery packs, many individual batteries were also replaced to protect the rest of the pack.

Reliability Issues

High temperatures contributed to the problems with the electrical components on the trams. The components generated heat themselves, as well as being exposed to the high ambient temperature at the seashore. Many of these were mounted very close together and the ventilation system was not able to provide adequate cooling. As a result, the electrical components would overheat and fail; and, the park electrician often was called to replace blown fuses several times a day. These failures caused significant disruptions to tram operations and the ability to maintain a schedule.

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[*] *Lessons Learned: Battery-Electric Transit-Bus Opportunity Charging: Interim Report*, EPRI, Palo Alto, CA, and the US Department of Energy, Idaho Falls, ID: 1999. TE-114255

[†] www.batteryuniversity.com

Normally, delays would only aggravate park visitors. However, in the event of an emergency, such as an electrical storm when the beach must be evacuated quickly, both trams are necessary to handle the passenger load. In such cases, reliability problems presented a visitor safety hazard as well.

Lessons Learned: Project Management

The management of the project was evaluated to determine what types of lapses occurred during the implementation of the Cape Cod trams. The findings indicate steps NPS staff can take to avoid some of the problems Cape Cod National Seashore encountered during the vehicle procurement processes. This section provides lessons for how NPS project managers can facilitate future procurements.

Recognize that procuring an innovative vehicle involves risk

The use of alternative vehicle propulsion technologies is becoming more common, but many of the technologies involved involve greater risk in comparison to more conventional propulsion technologies. Cutting edge technologies have the potential to bring great rewards to parks and park visitors, but bring a greater risk of more complications. In one sense, electric vehicles are not novel, having existed in various forms for nearly a century; and, the supporting technologies are fairly well established. However, the development of a new vehicle – even one based on proven technologies – has inherent risks. While it is important to understand the stage of maturity of the underlying technologies, it is more important to recognize and appreciate the difference between a proven vehicle and an early prototype.

Not all advanced technology vehicles involve high-risk, and some are more appropriate for a park environment than conventional vehicles. However, parks seeking innovative vehicles, especially those that are more a prototype than a production model, should be prepared to deal with delays, possible design changes, and other obstacles intrinsic to any new vehicle development, even one that is based largely on an existing design. Similarly, park managers should anticipate a need to address operations and maintenance issues with respect to vehicles that have not accumulated a substantial record of performance in settings comparable to intended park use.

Cape Cod National Seashore realizes, in hindsight that their experience with the electric trams was frustrating because they had entered the project assuming the trams were sufficiently proven to perform without significant problems, whereas others viewed the project as a technology demonstration and evaluation opportunity. The other participants were more aware of the risks, and viewed the project as a demonstration effort building toward commercialization of hybrid-electric propulsion technology for transit vehicles, such as buses and trams. Park staff had a very limited understanding of the potential problems and delays. They assumed that the acquisition would be able to follow a fixed timeline and did not anticipate the complications that arose. Discussions with partners regarding goals and motivations will help to ensure everyone shares common project understandings and expectations before committing to a partnership.

Identify performance needs for the expected vehicle usage and operating environment

At the outset of a project, an assessment of the anticipated vehicle uses should be conducted. Factors such as passenger load, daily service hours, terrain, and weather should be reviewed, to develop an in-depth understanding of what the vehicles must be able to tolerate and do under actual park operating scenarios and conditions. Such an analysis can then be used to generate a comprehensive, detailed list of criteria the vehicles must meet. Establishing performance-based standards for the vehicles accomplishes several things. It ensures the procurement specifications match the NPS needs for the vehicles. It clarifies the NPS position to the other stakeholders, giving them a better understanding of NPS goals. It also gives the technical contractors some flexibility with regard to vehicle design and components, as long as the performance criteria are met.

Many of the performance criteria that should be consider are addressed in the "Vehicle Design Specifications" section of this report; these include motor power, vehicle range, resilience to the elements (particularly in seaside environments), and safety components.

Assess technology readiness and support needs

Park staff should conduct "due diligence" to learn about vehicle manufacturers, to determine their track record with similar projects and to assess the maturity and performance record of candidate vehicles in comparable settings. The NPS should make sure that all relevant topics are addressed in the procurement specifications. This includes not only the design of the vehicle, but also supporting infrastructure needs, and maintenance and repair provisions, including training and service manuals, "as-built" drawings, replacement part descriptions / sources, and inventory levels for consumables and long-lead time items.

Set a realistic timetable and have a backup plan

Most new vehicle development projects are bound to have problems and delays, especially those involving advanced technologies. Table 1 shows typical time periods from the date an order is placed until the delivery of buses and trams. An additional 6 to 12 months is usually necessary to develop the specifications, issue the solicitation, and award a contract. If the timeframe proposed falls significantly outside this range, manufacturers should have well-documented reasons why vehicles can be produced so quickly or alternatively, why a longer timeframe is warranted.

Perhaps the biggest cause of the Cape Cod tram problems was the short timeframe for tram delivery. AVS was given less than six months to deliver the trams. Six months is less time than typically is required to acquire a production model vehicle. Parks should establish a realistic timeframe for vehicle construction and delivery, which may require the NPS to plan farther ahead when scheduling the replacement of vehicles.

Table 1
Approximate Bus/Tram Delivery Schedules
Source: Volpe National Transportation Center,

Bus/Tram Type	*Time from Order Placement to Delivery*
Diesel Production Vehicle	*1 to 1.5 years*
Diesel Production Vehicle with Modifications	*1 to 1.5 years*
Alternatively Fueled Production Vehicle	*1 to 1.5 years*
Alternatively Fueled Production Vehicle with Modifications	*1.5 to 2 years*

The project implementation schedule needs to allow for flexibility from the outset to avoid the schedule-driven compromises and concessions that the park had to make to ensure it would have vehicles to serve visitors. Parks also should have a backup plan in place that can be implemented in the event new vehicles cannot successfully complete acceptance tests and be delivered on time. Parks should be willing to use interim measures rather than accept vehicles that do not meet the project specifications or that have not been thoroughly tested. Having a contingency plan helps the NPS project manager prevent from being forced to accept vehicles and then rely on warranty provisions to correct any deficiencies.

Verifying that vehicles meet all performance specifications and have been fully tested before delivery ensures that responsibility for completing any modifications and/or repairs remains with the manufacturer rather than being shifted to NPS. The staff at Cape Cod National Seashore was placed in a difficult position when time ran out on the planned schedule; they were compelled by the lack of contingency shuttle service alternatives to accept the trams without road testing and then address subsequent repair needs subsequently. To its credit, AVS worked with the park to address tram deficiencies after the vehicles were delivered but the design shortcomings could not be overcome.

Review proposed changes carefully, from an overall systems perspective

At the outset of the tram project, the park knew it wanted an environmentally sensitive vehicle, but had limited knowledge and experience with hybrid or electric vehicles. Park staff necessarily relied on the expertise and judgment of the other participants. The NPS project manger relied on EHVP and AVP staff to provide the necessary expertise and technical project oversight; whereas, AVP staff viewed their involvement as aiding a project in distress through brokering the financial resources needed to retrofit the trams with microturbines as originally envisioned. Whereas all parties worked diligently to achieve a positive outcome, none anticipated the dire cascade of events from a seemingly simple switch to a battery-only redesign. Nor was the need for significant technical involvement and representation by government staff anticipated. Conceptually, the task was simple: install an existing prototype hybrid-electric bus propulsion system in a tram chassis.

Many of the problems that the Cape Cod trams exhibited were, in retrospect, predictable and preventable. For example, it is clear that eliminating the microturbine would significantly reduce the range of the trams. Placing the fast charger one mile away from the service route may have been the only option available, but it proved to not be a viable decision. It appears that delivery schedule and budgetary considerations motivated technical decisions for short term advantage at the expense of longer term considerations.

Provide methods for enforcing vehicle performance and quality requirements

The main priority should be to ensure that the NPS receives vehicles that meet its needs. It is not enough to set desired performance standards; parks and/or their authorized representatives must ensure those standards are met. Whereas having detailed vehicle performance requirements in the procurement specifications is essential, the NPS should, however, go beyond this and ensure that the procurement contract and all other project documents establish clear, measurable and enforceable criteria that the vehicles must meet prior to acceptance. This eliminates ambiguity in contract provisions, and clarifies the positions of the parties. In the event the manufacturer fails to satisfy the requirements, remedies should also be specified in the contract.

Maintain good communication among project participants

The park staff, technical advisors, and contractors should meet regularly to discuss scheduling and design changes. The input from people with different perspectives and expertise will help to identify existing and potential problems during the design and construction of the vehicle. Park staff needs to be involved in the process because they know the operating conditions in the park and their own abilities and resources to maintain and operate the vehicles – facts that need to be conveyed to the other stakeholders. Furthermore, when the park staff is given the opportunity to hear about setbacks as early as possible, they have more time to work around the problems and develop interim solutions to prevent compounded mistakes later on.

Lessons Learned: Vehicle Specifications

Despite the problems with the Cape Cod National Seashore trams, advanced technology hybrid and electric vehicles have excellent potential for future use. This section provides suggestions for preparing vehicle specifications as part of a successful procurement. Before implementing any of these suggestions, designers and engineers should evaluate how these criteria will affect systems both on vehicles and the supporting infrastructure. The included standards and references are intended to be applicable to any heavy-duty electric vehicle.

Specify for sufficient motor power and vehicle range

The first priority in designing a hybrid or electric vehicle is to provide ample power reserves for acceleration, particularly uphill, and to ensure a useful range. There are several different methods that can be used together or separately to accomplish this goal.

Motor Power

The motor needs to have enough power to accelerate the vehicle and climb hills on the service route. Newer electric motors are available that run on the same input voltage as older motors but have greater power output. The general comparisons in Figure 2 can be used to evaluate whether a proposed motor will be sufficient to handle the weight of a particular vehicle, although the characteristics of the service routes for these vehicles are unknown. Ultimately, the vehicle designer will choose an appropriate motor based on acceleration, grade climbing ability, and vehicle range requirements.

Hybrid Design

Another option for ensuring adequate power is to follow the original concept for the Cape Cod hybrid trams and include a CNG microturbine, or other source to complement battery power. The microturbine can provide additional power for climbing hills, and also can charge the batteries during operation. The microturbine also helps to avoid problems that result from the use of a fast charger. However, including a CNG microturbine adds complexity to the vehicle design and requires vehicle maintenance staff to perform a more complicated service routine. The specific requirements of a service route should be carefully evaluated to determine if the benefits of the CNG microturbine outweigh the added complexity.

Battery Swapping

Another technique that has worked well in some cases is to exchange battery packs when the capacity of the in-service battery pack has been used, in lieu of fast charging. The vehicle is only out of commission during the time that it takes to remove one battery pack and replace it with a fully charged pack (typically 20-25 minutes). Since a battery pack does not have to be returned to service immediately, it can always be slow charged in a manner that is less likely to cause damage and performance degradation. Battery swapping is easier to implement safely than rapid charging, but it requires the investment in additional battery packs and infrastructure for their storage and simultaneous charging. Further, the cost of maintenance staff time required to swap out battery packs needs to be considered.

Battery Chemistry

Advances in battery technology continue to further the life capacity and charging capacity, and to shorten charging times. All types of batteries and characteristics (e.g., power capacity, cooling requirements, and compatibility with trickle and fast charging) should be considered when selecting battery packs. Several different battery chemistries are now available that can be used with heavy-duty vehicles. The battery chemistry should be selected to provide sufficient energy with a reasonable amount of maintenance. More details on comparing battery chemistries are available in Appendix 1.

Identify special needs or operating conditions in the procurement specifications

Park vehicles often operate in harsh environments. The Cape Cod trams were exposed to heat, humidity, saltwater, and sand in the seashore environment. The trams were not protected from these conditions, leading to damage to the motors, batteries, and other electrical components. Before preparing vehicle specifications, the NPS should evaluate the operating environment for difficult conditions such as extreme heat or cold, extreme dryness or humidity, rough roads, mountainous terrain, and other factors. The vehicle specifications should include requirements that the vehicle can operate in the prevailing conditions.

Appendix 1 includes suggestions for standards and practices to consult for the design of heavy-duty electric vehicles to operate in extreme conditions. They are primarily geared to a seashore environment, but some are universally applicable.

Ensure the quality of wiring and grounding

All wiring should be done to the standards set in the National Electrical Code. All charging should be done with a Ground Fault Circuit Interrupter, and instructions for safely connecting and maintaining a battery pack should always be followed. The Society of Automotive Engineers (SAE) Recommended Practice J1797, "Recommended Practice for Packaging of Electric Vehicle Battery Modules," suggests having both the battery and vehicle manufacturers approve the high voltage connectors to be used in a system. Vibration, temperature, and the frequency with which the connectors will be connected / disconnected should be taken into consideration. SAE J1797 also recommends that the connectors be able to carry the maximum expected current without generating enough heat to damage the batteries.

Specify a suspension system that ensures safety during maintenance and repairs

Many of the repairs and maintenance performed on the trams was performed on the side of the road where the vehicles had broken down. In such situations, where repair work needs to be performed outside of a controlled maintenance facility, it is important to have a reliable vehicle suspension system that will not fail unexpectedly. This applies to any vehicle, not only electric and hybrid-electric vehicles, and to any type of suspension system. Suspension systems on NPS vehicles should be designed to be reliable. However, support jacks should be used as redundant supports whenever possible.

Incorporate infrastructure requirements into the procurement specifications

Ongoing vehicle operations require a comprehensive support infrastructure. This includes such elements as a garage to protect vehicles from harsh environments when not in use, and a charging station that is safe and in a location that minimizes disruptions to service. The design team should establish what infrastructure components are to be supplied as part of the procurement, and what the specifications of those components will be. Rapid charging stations, for example, should be located away from areas with heavy pedestrian traffic and should be fenced in and clearly marked as high voltage areas.

Require maintenance training and manuals in the procurement specifications

Provisions for maintenance training and accurate manuals for the park maintenance staff should be included in the procurement specifications. These will greatly assist the NPS maintenance staff in working with unfamiliar technologies and new vehicles. If the park staff had been provided with accurate "as-built" manuals and wiring diagrams, they could have avoided much of the trial and error approach needed to make repairs to the trams. NPS should also consider making arrangements for the vehicle manufacturer to provide formal maintenance training. Hindsight shows that proper training can confer significant benefits during the operation and maintenance of vehicles, and can significantly reduce delays and frustration in the long term.

When working with new technologies, it is not unusual to have difficulties with maintenance and locating replacement parts. The maintenance staff should be made aware of the typical challenges associated with such vehicles before the project is undertaken, so their expectations will be set accordingly and they will be less likely to become frustrated later.

Conclusion

Electric and hybrid-electric vehicles have great potential for providing environmentally sensitive transportation, particularly in national parks. Such vehicles, however, present certain challenges because these often involve newer technologies and/or entail vehicle modifications that can cause changes and delays in the design and manufacturing phases. NPS staff should be aware of these possibilities, so they can undertake the procurement process in an informed manner and can implement measures that will help to mitigate the consequences of problems that arise. The Cape Cod electric trams underscore the importance of ensuring that design modifications be carefully reviewed and assessed to ensure that vehicle performance requirements will not be compromised inadvertently through a "quick fix" solution. The electric trams at Cape Cod National Seashore serve as a useful example to highlight some of the procedural and technical issues of which NPS project managers need to be aware, as these can affect the ultimate success or failure of alternative fuel vehicles – especially electric and hybrid-electric vehicles, which tend to be far less tolerant of varied duty cycles and operating conditions than gasoline and diesel powered vehicles.

Appendix 1 – Additional Technical Information

Battery Damage from Fast Chargers

Rapid charging is accomplished by applying a high current during the beginning of the charge cycle. As a battery absorbs more energy, charging efficiency decreases. If the current remains high, the excess energy is converted to heat, which increases the pressure in the battery cell. If the temperature gets too high, oxygen and hydrogen will be vented, depleting the electrolyte and decreasing the storage potential of the battery. Lead-acid batteries must be specifically designed for fast charging. Even if the charger uses the ideal current algorithms for rapid charging lead-acid batteries on batteries designed for slow charge only, the initial burst of high current power would heat up the conductive path, damaging the batteries.

However, rapid charging can be used effectively if proper batteries and charging techniques are observed. These techniques are highly dependent on the speed of charging and the battery chemistry. The vehicle, battery, and charger manufacturers should all work together to develop or identify chargers that will provide adequate support for the vehicle.

Battery Chemistry

Sealed lead-acid batteries are not the only battery type suitable for heavy-duty electric vehicles. Flooded-cell lead-acid as well as flooded-cell nickel-cadmium (Ni-Cd) batteries are commonly used in heavy-duty electric vehicles[*]. The advantage of a sealed battery is that it requires less maintenance than a flooded-cell battery. The flooded-cell batteries lose some electrolyte due to out gassing during the final stages of charging. This lost material must be periodically replaced. However, sealed lead-acid batteries have a shorter lifespan and are more sensitive to overcharge, over-discharge, and thermal imbalances than flooded-cell batteries. Sealed and flooded lead-acid batteries have comparable costs, but the flooded Ni-Cd batteries are more expensive. However, Ni-Cd batteries have a higher energy density, are more tolerant of deep cycling, and can be used at lower temperatures.

Battery technology for powering heavy-duty vehicles is undergoing research and development, with new nickel metal hybrid, lithium-ion, and high temperature sodium, nickel-chloride battery chemistries entering the commercial marketplace. SAE paper No. 931780, “Comparison of Advanced Battery Technologies for Electric Vehicles,” provides some guidelines for choosing the appropriate battery chemistry based on economics and predicted vehicle range. Updated performance plots as well as cost information should be sought from manufacturers before conducting a specific analysis.

Safety Suggestions for High Voltage Battery Packs

Chapter 3 of the U.S. DOT Federal Transit Administration *“Design Guidelines for Bus Transit Systems Using Electric and Hybrid Electric Propulsion as an Alternative Fuel”*[†] provides design

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[*] *Lessons Learned: Battery-Electric Transit-Bus Opportunity Charging: Interim Report*, EPRI, Palo Alto, CA, and the US Department of Energy, Idaho Falls, ID: 1999. TE-114255

[†] *Design Guidelines for Bus Transit Systems Using Electric and Hybrid Electric Propulsion as an Alternative Fuel*, U.S. DOT Federal Transit Administration, March 2003, FTA Report No. DOT-FTA-MA-26-7071-03-1

guidelines for high voltage battery systems. In general, battery wires should be individually covered and separated from each other by 4 to 6 inches. The cables should not be laid near sharp edges and should be attached to an insulated surface every 6 to 8 inches. Battery surfaces should be protected from exposure to water and salt. The connectors should be arranged such that if these do get wet they will drain and dry quickly. All metal surfaces should be separated from the batteries by at least six inches to prevent accidentally creating a circuit through metal tools or other parts. Lastly, the entire battery-pack should be covered with an insulated surface.

Other On-board Energy Storage Options

For hybrid vehicles, a number of other energy storage technologies are available that can replace or reduce the use of batteries. These include ultra-capacitors, hydraulic systems, flywheels, and combinations thereof.

Design Suggestions for Vehicles Used in Harsh Environments

Vehicles should be designed according to the environmental guidelines described in the SAE Recommended Practice J1211, "Recommended Environmental Practices for Electronic Equipment Design." The guidelines give suggestions for testing components for the effects of temperature, humidity, salt spray atmosphere, immersion and splash, dust, sand and gravel bombardment, and other hazardous environmental conditions. All components must be certified to withstand the environmental conditions for the vehicle's environment or suitable protection must be built into the vehicle.

J1211 was, however, written for vehicles powered by an internal combustion engine. Each practice must be re-evaluated and modified to suit an electric vehicle. If standards for the environmental practices for electric vehicles are developed, they will supersede J1211. ASTM also has two standards for testing components' behavior in a salt spray atmosphere: ASTM B117, "Standard Practice for Operating Salt Spray (Fog) Apparatus," and ASTM G85, "Standard Practice for Modified Salt Spray (Fog) Testing."

Additional guidelines for safeguarding the electrical systems in beach environments can be found in the CFR Title 46, Shipping, which was developed for marine vehicles. Some of the listed requirements may be more extreme than may be necessary, but will provide a safe solution in the absence of other information.

Appendix 2 - Applicable Codes, Standards and Recommended Practices

1. Code of Federal Regulations (CFR), Title 49, Transportation. http://www.access.gpo.gov/cgi-bin/cfrassemble.cgi?title=200349
2. CFR, Title 46, Shipping: Part 111 – Electric Systems General Requirements
3. American Iron and Steel (AISI) Standards
4. All subdivisions of the current National Fire Prevention Association Codes including National Electric Codes and Regulations. http://www.nfpa.org/Codes/index.asp
5. National Fire Protection Association 70 (National Electric Code article 625).
6. Society of Automotive Engineers (SAE) J551/1 - Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles and Devices (50-Hz to 18-GHz)
7. SAE J551/2 – Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles, Motorboats, and Spark–Ignited Engine-Driven Devices
8. SAE 551/4 – Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles and Devices, Broadband and Narrowband, 150 kHz to 1000 MHz
9. SAE 551/5 Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz to 30 MHz
10. SAE J551/11 Vehicles Electromagnetic Immunity – Off Vehicle Source
11. SAE J551/12 Vehicles Electromagnetic Immunity – On-Board Transmitter Simulation
12. SAE J551/13 Vehicle Electromagnetic Immunity – Bulk Current Injection
13. SAE J1113 - Electromagnetic Compatibility
14. SAE J1211 – Recommended Environmental Practices for Electronic Equipment Design
15. SAE J1654 - High Voltage Primary Cable
16. SAE J1673 - High Voltage Automotive Wiring Assembly Design
17. SAE J1742 - Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harnesses - Test Methods and General Performance Requirements
18. SAE J1718 - Measurement of Hydrogen Emissions from Battery-Powered Passenger Cards and Light Trucks During Battery Charging
19. SAE J1772 – Electric Vehicle Conductive Charge Coupler
20. SAE J1773 – Electric Vehicle Inductively Coupled Charging
21. SAE J2344 - Guidelines for Electric Vehicle Safety
22. SAE J2293 - Grid Connected Communications Protocol
23. SAE J2294 - Recommended Practice for Test and Performance of Auxiliary Fuses for High Voltage Road Vehicle Wiring Systems
24. ANSI/IEEE 62.41.1 - IEEE Guide on the Surge Environment in Low-Voltage (1000V and Less) AC Power Circuits

25. ANSI/IEEE 62.41.2 – IEEE Recommended Practice on Characterization of Surges on Low-Voltage (1000V or Less) AC Power Circuits

26. ANSI/IEEE 62.45 – IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000V or Less) AC Power Circuits

27. CISPR 12 – Vehicles, Boats, and Internal Combustion Engine Driven Devices - Radio Disturbance Characteristics - Limits and Methods of Measurement for the Protection of Receivers Except those Installed in the Vehicle/Boat/Device itself or in Adjacent Vehicles/Boats/Devices

28. CISPR 25 – Radio Disturbance Characteristics for the Protection of Receivers Used on Board Vehicles, Boats, and on Devices – Limits and Methods of Measurement

29. IEC 61000-4-4 Electromagnetic Compatibility (EMC) – Part 4: Testing and Measurement Techniques – Section 4: Electrical Fast Transient/Burst Immunity Test

30. IEC 61000-3-2 – Limits for Harmonic Current Emissions (Equipment Input Current <= 16A per Phase)

31. ISO 11451 – Road Vehicles – Vehicle Test Methods for Electrical Disturbances by Narrowband Radiated Electromagnetic Energy, Parts 1-4

32. Federal Motor Vehicle Safety Standards (FMVSS) 305 - Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection http://www.access.gpo.gov/nara/cfr/waisidx_01/49cfr571_01.html

33. Underwriters Laboratories 2202 Electric Vehicle Charging System Equipment http://ulstandardsinfonet.ul.com/scopes/2202.html

34. Underwriters Laboratories 2231-1 and 2 Personnel Protection Systems http://ulstandardsinfonet.ul.com/scopes/2231-1.html http://ulstandardsinfonet.ul.com/scopes/2231-2.html

35. Underwriters Laboratories 2251 Plugs Receptacles and Couplers. http://ulstandardsinfonet.ul.com/scopes/2251.html

36. Underwriters Laboratories 746-C Polymeric Materials Used In Electric Equipment Evaluations. http://ulstandardsinfonet.ul.com/scopes/0746C.html

37. ASTM B117-03 “Standard Practice for Operating Salt Spray (Fog) Apparatus”

38. ASTM G85-02 “Standard Practice for Modified Salt Spray (Fog) Testing”

Appendix 3 - Acronyms

ANSI	American National Standards Institute
ASTM	American Society for Testing Materials
AVS	Advanced Vehicle Systems
CACO	Cape Cod National Seashore
CISPR	International Special Committee on Radio Interference
CNG	Compressed Natural Gas
DARPA	Defense Advanced Research Projects Agency
EPRI	Electric Power Research Institute
GFCI	Ground Fault Circuit Interrupter
GVWR	Gross Vehicle Weight Rating
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
mpg	Miles Per Gallon
Ni-Cd	Nickel-Cadmium
NPS	National Park Service
SAE	Society of Automotive Engineers
TMP	Transportation Management Program
UL	Underwriters Laboratories

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14. ABSTRACT
In seeking to obtain environmentally friendly replacement vehicles for its parking shuttle service, Cape Cod National Seashore set out to procure two hybrid-electric trams in 1998. Ultimately, battery-powered trams were delivered with multiple safety and performance problems that were never successfully remedied. This analysis examines the causes of these deficiencies and identifies several critical “lessons learned” that will assist other parks to avoid similar problems when undertaking future procurements of similar vehicles.

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